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Bioenergy industries development in China: Dilemma and solution

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ABSTRACT

Having 2.8×10^8–3.0×10^8 t/a of wood energy, 4.0×10^6 t/a of oil seeds, 7.7×10^8 t/a of crops straw, 3.97×10^9 t/a of poultry and livestock manure, 1.48×10^8 t/a of municipal waste, and 4.37×10^{10} t/a of organic wastewater, China is in possession of good resource condition for the development of bioenergy industries. Until the end of 2007, China has popularized 2.65×10^7 rural household biogas, established 8318 large and middle-scale biogas projects, and produced 1.08×10^{10} m^3/a of biogas; the production of bioethanol, biodiesel, biomass briquettes fuel and biomass power generation reached to 1.5×10^6 t/a, 3.0×10^5 t/a, 6.0×10^4 t/a and 6.42×10^9 kWh, respectively. In recent years, bioenergy industries developed increasingly fast in China. However, the industrial base was weak with some dilemma existing in raw material supply, technological capability, industry standards, policy and regulation, and follow-up services, etc. From the viewpoint of long-term effective development system for bioenergy industries in China, a series of policy suggestions have been offered, such as strengthening strategy research, improving bioenergy industries development policies and plan, enhancing scientific research input, persisting in technology innovation, establishing product quality standard, improving industrial standard system, opening market and accelerating commercialization, etc. It is expected that the advices mentioned above could be helpful for the improvement of bioenergy industries development.

Contents

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1. Introduction

Biomass refers to all the earth's living matter growing through the photosynthesis, which includes animals, plants, microbes, and the organic materials generally that is excreted and metabolized by them [1]. Bioenergy is the energy converted from solar energy by chlorophyll and stored in green plants [2,3]. It is currently regarded as the most potential renewable energy source for it is the only renewable carbon resource and it can be directly converted to liquid fuel, which can contribute to the world's sustainable energy supply in the future [4–7]. To explore and utilize bioenergy is significant to mitigate energy shortage, improve environment quality, control greenhouse effect, and promote rural economic and social sustainable development; it is one of the effective and important methods to solve the resources, environment, and economic problems that human beings are facing currently [8–10].

China is one of the world's largest energy consumers that imported 1.63×10^8 t of crude oil in 2007, and the dependency on foreign oil reached to 46.6% [11]. Statistical data indicated that the proved economic recoverable reserves of coal, oil and natural gas are 1.15×10^{11} t, 2.04×10^9 t, and 2.45×10^{12} m^3, respectively in China, up to the end of 2006 [12]. Calculated by the exploited speed in 2006, i.e. coal: 2.38×10^9 t/a, oil: 1.85×10^8 t/a, and natural gas: 5.85×10^{10} m^3/a [13], each can only be exploited by 48 a, 11 a and 41 a, which are much lower than the world average, i.e.147 a, 40.5 a and 63.3 a, respectively [14]. China is the second largest greenhouse gas emitter. Although it has not assumed any emission obligation, with entering the post-Kyoto Protocol era, China's greenhouse gas emission has attracted broad attention from countries all over the world, and China is facing rising pressure to reduce emission [15,16]. Developing bioenergy will be an inevitable choice for sustaining economic growth, for the harmonious coexistence of human and environment as well as for the sustainable development with adjusting energy consumption structure, maintaining national energy security, and reducing environmental pollution and greenhouse gas emission, effectively [17–19].

2. Current situation of biomass resources in China

2.1. Forest biomass

Forest biomass is the wood resources produced in the forestry production, including fuelwood, wood processing waste, and oilseeds, etc. [20]. The sixth National Forest Resources General Investigation showed that 1.75×10^8 hm^2 of forest and 1.25×10^{10} m^3 of growing stock are in existence in China, and 2.8×10^8–3.0×10^8 t of biomass resources can be supplied during the production process (Table 1) [21]. In China, there are approximately 5.4×10^7 hm^2 of barren hills and wasteland suitable for afforestation, and 1.0×10^8 hm^2 of marginal land suitable for developing energy plant. Calculated with 20% of utilization rate and 20 t/hm^2 of yield, 4.0×10^6 t of oilseeds can be supplied annually.

2.2. Crops straw

Straw refers to the residues after agricultural crop harvest, and it is the main byproducts of agriculture production. As straw yield has not been included in the government statistics, it generally can be calculated by the yield of agricultural crop [22] (Table 2). According to the straw resources utilization structure (Table 3), there are 4.14×10^8 t of straw resources can be used as energy in China annually.

2.3. Poultry and livestock manure

Poultry and livestock manure is a kind of important biomass resource, which is the main feedstock for biogas fermentation. Based on the poultry and livestock species, manure quantity, and breeding cycle [23,25,26], China's poultry and livestock manure reached to about 3.97×10^9 t in 2007, equivalent to 6.5×10^8 tce (Table 4).

2.4. Municipal waste and organic wastewater

Municipal waste means the solid waste generated from daily life. By using advanced technologies such as incineration power generation and landfill gas recycle, waste utilization industry can be realized. The municipal waste clearance amount was 1.52×10^8 t in 2007, including 7.63×10^7 t of sanitary landfill [23]. 5.87×10^6 m^3 of landfill gas will be generated which is estimated by IPCC recommended model [27].

Organic wastewater can be divided into domestic wastewater and industrial wastewater. Drainage amount of China's industrial wastewater reached to 1.40×10^{10} t, and COD reached to 1.43×10^7 t in 2006. If all wastewater is disposed by anaerobic fermentation, 1.33×10^7 m^3 of biogas will be generated which has been calculated with the IPCC recommended formula [28].

3. Bioenergy industries development status in China

Bioenergy is the secondary energy processed and converted from biomass, including biogas, bioethanol, biodiesel, biomass power generation, and biomass briquettes fuel, etc. [29]. With the increasing scarcity of fossil fuel resources, the demand for greenhouse gas reduction and environmental protection all over the world, one of the most important energy strategies is to

Table 1
Amount of forest biomass resource in China.

Type	Plant area	Supplied biomass resources	
		Resource type (unit)	Yield
Fuelwood forest	3.0×10^6 hm^2	Wood energy ($\times 10^8$ t)	0.8–1.0
Shrubbery	4.5×10^7 hm^2	Wood energy ($\times 10^8$ t)	1.0
Large sapling and middle age forest	5.7×10^7 hm^2	Wood energy ($\times 10^8$ t)	1.0
Oleaginous forest	6.1×10^6 hm^2	Oilseeds ($\times 10^4$ t)	400
Total		10^8 t	2.8–3.0

Table 2
Amount of main crops straw resources in China in 2007.

Type		Crop yield ($\times 10^4$ t) [23]	Grain straw ratio	Straw yield ($\times 10^4$ t)
Grain	Rice	18603.4	1.0	18603.4
	Wheat	10929.8	1.0	10929.8
	Corn	15230.0	2.0	30460.1
	Legume	1720.1	1.5	2580.155
	Tuber	2807.8	1.0	2807.804
	Others	869.1	1.5	1303.65
Oil plant	Peanut	1302.8	2.0	2605.6
	Rapeseed	1057.3	2.0	2114.6
	Sesame	55.7	2.0	111.4
	Others	153	2.0	306
Cotton		762.4	3	2287.079
Bast fiber plant		72.8	2	145.6644
Sugar crop	Sugar cane	11295.1	0.1	1129.505
	Sweet beet	893.1	0.1	89.31244
Total		65752.4		75474.08

Table 3
Main usage of straw resources in China.

Usage	Percentage [24] (%)	Resource quantity ($\times 10^8$ t)
Fuel for life	39.6	29887.74
Livestock feed	27.5	20755.37
Industrial raw material	2.7	2037.8
Straw return and gathering loss	15	11321.11
Discarded and burned	15.2	11472.06
Total	100	75474.08

Table 4
Poultry and livestock manure resources in China.

Animal species	Breeding quantity ($\times 10^4$)	Manure discharge rates	Breeding cycle (day)	Excrement amount ($\times 10^4$ t)
Cattle	13944.2	8.2 t/a	365	114342.5
House	719.5	5.9 t/a	365	4244.8
Donkey/mule	730.6/345.1	5.0 t/a	365	5378.1
Pig				
Sale	68050.4	5.3 kg/d	300	105200.1
Stock	49440.7		365	95643.1
Chicken	731852.17	0.10 kg/d	55	40251.87
Sheep	36896.6	0.87 t/a	365	32100.1
Total				397160.6

develop bioenergy. Chinese government paid great attention to the bioenergy development. On January 1st 2006, *PRC Law of Renewable Energy* has been implemented, and later a series of related regulations, technology specifications and management measures have been enacted and implemented [19]. On October 30th, 2008, in order to push crop straw energy utilization and incubate application market for straw energy products, Ministry of Finance of PRC issued *Provisional Measures for Administration of the Subsidy Capital for Crop Straw Energy Utilization*, which provided special subsidy for enterprises dedicated to briquettes fuel, gasification and carbonization [30]. Under the guidance of government policies, bioenergy industries developed rapidly and achieved good effect in China.

3.1. Biogas

Biogas is a flammable mixture comprising primarily CH_4 produced by bacterial anaerobic fermentation of biomass and waste, such as crop straw, manure or organic wastewater [31]. Biogas industry is a benign process of industrial circulation which produces biogas, slurry and residues through anaerobic fermentation of waste from industrializing, farming and daily living, and later, the biogas, slurry and residues can be utilized in various industries and daily life, inversely [32].

In the 1980s, biogas digesters with the principles of *gas storing through draining* and *gas exhausting by water intaking* appeared in southeast littoral areas of China, which was a ground-breaking initiative of water-pressure biogas digester [33]. At present, it has been developed many standardized biogas digesters in China, such as Hydraulic Cylinder Digester, Separated Floating Bell-Type Digester, Meandering Stream Fabric Digester, Prefabricated Block Digester, and Spheroidal Digester, etc. [34,35]. Also it has established various efficient recycling eco-agricultural models of biogas comprehensive utilization [36]. Up to the end of 2007, it has developed 2.65×10^7 of household biogas digesters, built 2.66×10^4 of poultry-and-livestock-farm biogas projects all around China [37], and produced $1.08 \times 10^{10}\,m^3$ of biogas (Fig. 1), which alternated 1.98×10^7 t of coal, reduced 1.27×10^7 t of CO_2 emission, and reduced 2.65×10^5 t of SO_2 emission.

On November 14th, 2008, Ministry of Agriculture of PRC planned to invest three billion of RMB to construct rural household biogas digester, rural biogas service system, and joint-households biogas projects in intensive rearing livestock areas for post-earthquake reconstruction and economic recovery after financial crisis, which will accelerate the development of China's biogas industry [38].

In general, the technology of biogas utilization has been ripe in China. Household biogas and poultry-and-livestock-farm biogas projects have been in the process of commercial popularization; and the sewage-treatment biogas project has entered the process of commercial demonstration and initial promotion. Biogas industry is in the post-growth stage with large popularized scale and significant economic and social profit.

3.2. Bioethanol

Bioethanol is ethanol derived from fermentation, distillation, and denaturalization of biomass, such as starchiness, sugariness and cellulose, etc. [39]. The development of bioethanol industry is an organic system which was composed of planting, collecting,

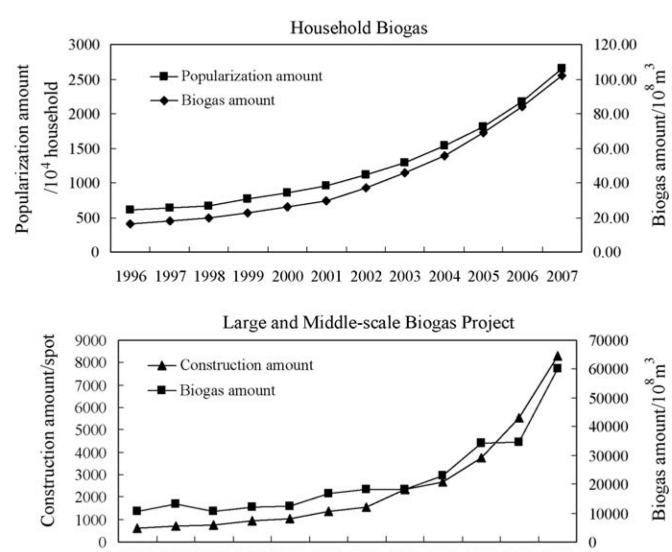


Fig. 1. Current situation of biogas industry in China.

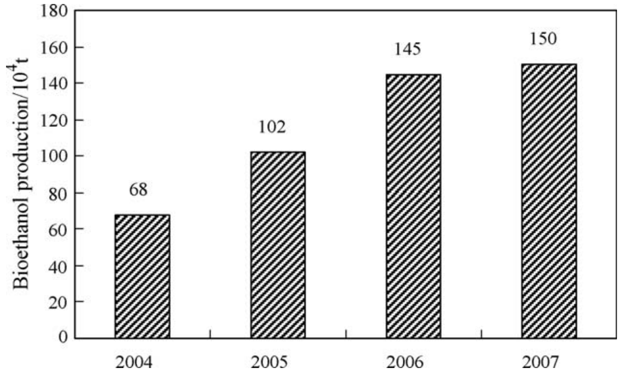


Fig. 2. Production of bioethanol in China.

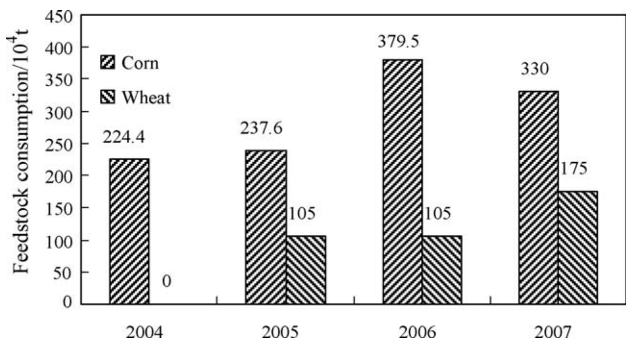


Fig. 3. Feedstock consumption of bioethanol in China.

transporting, processing, converting of materials, researching, producing of auxiliary materials, packaging and selling of product, byproduct utilization, etc.

The research and development of bioethanol began in 1930s in China. During the period of the War of Resistance against Japan, Henan Ethanol Company produced fuel ethanol for army's transportation. Currently, the process of bioethanol production from starchiness is mature in China. The most advanced process "half-dry" has been developed for bioethanol production successfully [40], and used for large-scale production. Since 2000, government has approved five enterprises to produce bioethanol using food and tapioca as feedstock. Bioethanol production capacity reached to 1.83×10^6 t/a in 2007, actual yield reached to 1.5×10^6 t/a (both with food as feedstock) (Figs. 2 and 3). China has become the world's third-largest bioethanol producer following USA and Brazil, and has developed demonstration projects of bioethanol transportation in 10 provinces (Table 5) [41].

In the sugar-based ethanol industry, China has successfully bred the hybrid sweet sorghum named *ethanol-sweet species* that is suitable for planting on 6‰ of carbonate alkalinity wasteland. The technologies of *Solid Fermentation Process* and *Fast Liquid-Fermentation Process* from sweet sorghum stalks realized 10% of feedstock conversion. And has established a 3000 t/a demonstration project of sweet sorghum bioethanol production (in Dongtai, Jiangsu Province) [42,43]. However, due to the high risk of industrialization of sweet sorghum bioethanol which was caused by both seasonally intermittent supply of sweet sorghum stalks and lack of the capability for fresh storage, from June of 2008, this kind of projects have gradually been suspended in China [44].

In the cellulose-based ethanol industry, several fuel ethanol production technologies from lignocelluloses have been developed, and the feedstock converting rate is over 18%. Now the cellulose-based ethanol is at demonstration stage of 10-thousand tons production capacity [45], and will gradually step into lead stage. *The 11th Five-year Plan of the Development of Renewable Energy* indicated that the government will keep increasing financial support to the development of cellulose-based ethanol industry [46], and will reduce related taxes or fees. Therefore, cellulose-based ethanol will become an inevitable trend of bioethanol industry in China.

3.3. Biodiesel

Biodiesel is an excellent substitute of petroleum-based diesel which was comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oil or animal fats using transesterification with higher alcohols [47].

The research and development of biodiesel have an early start in China. The experimental study of diesel produced from vegetable oil started in 1981. At the moment, several biodiesel production technologies have been developed successfully, using the feedstock of rap oil, Cormus Wilsoniana fruit oil, Jatropha Curcas oil, soybean oil, rice bran oil residue, and restaurant waste oil. And there into, the cutting-edge technologies include fatty acid alkyl esters production method, fatty acid synthesis by cottonseed oil residue, high-acid-value animal and plant fats azeotropic distillation methyl-esterification technology, and enzymatic biodiesel technology by using short-chain fatty acid esterification as acyl receptor [48,49].

Large-scale production of biodiesel started in early 21st century. And after the instruction by *State Council of PRC* and promotion by *National Development and Reform Commission of PRC* in 2002, private companies, large-scale state-owned enterprises and international energy enterprises started investing to develop and produce biodiesel. Up to September of 2008, there are

Table 5
Popularized regions of bioethanol in China.

Province	Popularized regions and beginning time	Source
Heilongjiang	October 1st 2004, Whole Province	Heilongjiang Hua-run Alcohol Co. Ltd.
Jilin	November 18th 2003, Whole Province	Jilin Fuel Ethanol Co. Ltd.
Liaoning	October 1st 2004, Whole Province	Jilin Fuel Ethanol Co. Ltd.
He'nan	December 1st 2004, Whole Province	Henan Tianguan Enterprise Group Co. Ltd.
Anhui	June 1st 2005, Whole Province	Anhui BBCA Biochemical Co.
Hubei	December 1st 2005, popularized in nine cities of Wuhan, Xiangfan, Jingmen, Suizhou, Xiaogan, Shiyan, Yichang, Huangshi, and E'zhou	Henan Tianguan Enterprise Group Co. Ltd.
Hebei	December 1st 2005, popularized in six cities of Handan, Shijiazhuang, Baoding, Xingtai, Cangzhou, and Hengshui	Henan Tianguan Enterprise Group Co. Ltd. supplied four cities Anhui BBCA Biochemical Co. supplied two cities
Shandong	January 8th 2006, popularized in seven cities of Ji'nan, Ji'ning, Tai'an, Heze, Liaocheng, Zaozhuang and Linyi	Anhui BBCA Biochemical Co.
Jiangsu	December 1st 2005, popularized in five cities of Xuzhou, Yancheng, Lianyungang, Suqian and Huai'an	Anhui BBCA Biochemical Co.
Guangxi	April 15th 2008, Whole Province	Guangxi COFCO Bio-energy Co. Ltd.

hundreds of biodiesel enterprises in China, and about 60 are over ten thousand ton-class. The production capacity exceeds 3.0×10^6 t/a, with waste oil, vegetable oil residue, restaurant waste oil as feedstock, and converting rate is over 75%. However, due to inadequate supply of feedstock, many companies are in downtime, and actual yield was merely 3.0×10^5 t/a with 4.0×10^5 t/a of feedstock consumption in 2007 [50].

From the view of industry life cycle, the biodiesel industry development is transiting into high-risk-and-high-profit growth stage from high-risk-and-low-profit start-up stage in China. One of the important strategies for biodiesel industry development will be to screen, breed and plant oil plants sensibly, to explore microalgae resources, to construct large-scale feedstock supply base, and to explore sustainable feedstock supply system.

3.4. Biomass power generation

Obtained by direct burning or conversion to flammable gases to generate power, biomass power generation technologies include direct combustion power generation, gasification power generation, garbage power generation, and biogas power generation, and mainly use agricultural, forest and municipal wastes as feedstock [36]. The research of biomass power generation started in the 1960s in China, and now the technologies are mature. The technologies of gasification power generation using sugar cane bagasse and rice husks, municipal wastes incineration power generation, and landfill gas power generation are at the stage of commercial popularization. And the technologies of biomass direct combustion power generation and crop straw gasification power generation are in demonstration (Table 6). Since 2000, large-scale state-owned enterprises, private enterprises and foreign-capital enterprises started investing biomass power generation projects, and the industry scale has started increasing rapidly. Up to the end of 2007, 87 biomass direct combustion power generation projects have been authorized by national and local government, more than 30 waste incineration power generation projects have been constructed, and above 40 small straw gasification systems have been popularized. The total installed capacity reaches to 3.0×10^6 kW with generated 6.42×10^9 kWh/a of electricity [37]. According to Mid-and-Long-Term Development Programming for Renewable Energy, biomass power generation total installed capacity will reach to 5.50×10^6 kW in 2010, and 3.0×10^7 kW in 2020 [46]. Biomass power generation industry has stepped into high-risk-and-high-profit growth stage in China.

3.5. Biomass briquettes fuel

Biomass briquetting is the process of converting low bulk density biomass into high density and energy concentrated fuel briquettes, including compressed briquetting, heated briquetting, and carbonized briquetting etc. [36]. The research and development of biomass briquettes fuels started in the middle of 1980s in China, and now the biomass briquetting equipments like screw extruding, piston stamping pressing, and roller compacting have been developed. The screw extruding technology is the most mature one in China, with the advantages of product high-density between 1100 kg/m^3 and 1400 kg/m^3 [51]. The demonstration of briquettes fuel was developed in Henan, Liaoning, Anhui, Shandong and Hebei Province, which drove rapid development of many equipment production enterprises and fuel processing enterprises. With great support and help from government environmental protection department and energy department, biomass briquettes fuel industry has developed rapidly, and the characteristics of enterprises active participation and government enhanced gradual orientation have appeared. However, the problems such as small scale and blind projects exist in the current enterprises. Now China has more than 30 different scale biomass briquettes fuel production enterprises, but the yield is only 5.0×10^5–6.0×10^5 t, which are mainly used in the direct burning of industrial boilers and domestic stoves [36,52]. The industry is at the start-up stage.

4. Dilemma of bioenergy industries development in China

In recent years, with government's positive encouragement and vigorous support, China's bioenergy industry developed rapidly and its industry scale enlarged gradually, which give rise to the obvious social and economic profit. However, from the viewpoint of the theory of industries development life cycle, China's bioenergy industry now stays at the transition stage from start-up to growth stage. The development of each sort of industry in this field lacks coordination, and some of them are falling into damping due to competition. Deficiency also exists in the aspects of feedstock supply, technology, industry standard, policy and regulation, and follow-up services, etc.

4.1. Rich biomass resources but shortage of feedstock supply

Feedstock resource is fundamental and a guarantee to bioenergy industries development. China is in possession of rich biomass resources, and theoretically, the prospect of supply is promising, but specific to industrial entity, biomass resources are in short supply. Feedstock shortages are key bottlenecks restricting the development of bioenergy industry (Table 7). Take bioethanol for example, there is 0.0933 ha of plough per capita in China, which is only 40% of world average [53]. In the premise of guaranteed *don't compete with people for food*, the excess grain hardly can satisfy the rapidly increased feedstock demand of bioethanol production. Producing bioethanol by sweet sorghum and cellulosic materials is the only way to develop sustainable bioethanol industry in China. The marginal land resources are rich in China. Approximately 1.0×10^8 hm^2 of saline-alkali soil, desertified land, swamp, beach and wasteland are suitable for energy plants. However, the cost of exploration and utilization is high, unit yield is low, produced sweet sorghum stalks are hard to store, and feedstock sustainable supply is difficult to realize. The agricultural waste resources are rich in China, but dispersed distribution results are difficult to collect and store. The biggest obstacle to develop

Table 6
Current situation of biomass power generation development in China.

Type	Specification	Installed capacity ($\times 10^4$ kW)	Generated electricity ($\times 10^8$ kWh)	Usage
Biogas power generation	Gas consumption rate 0.6–0.8 m^3/kWh	1.92	0.40	For plant own use
Direct-burning power generation	Stalk consumption rate 1.00–1.60 kg/kWh	45.8	23	Merged into State Grid
Gasification power generation	Gasification efficiency 78%, system power generation efficiency 28%	174	2.63	For plant own use
Waste power generation	Waste harmless disposal rate 52.2%	80	30	Merged into State Grid
Mixed-burning power generation	Mixed fuel ratio less or equal to 20%	16.4	8.6	Merged into State Grid
Total		316.2	64.23	

Table 7
Problems of China's bioenergy industries development.

Type	Biogas	Bioethanol	Biodiesel	Biomass power generation	Biomass briquettes fuel
Feedstock	Shortage in poultry and livestock manure for household biogas supply	Shortage in land resource, and constraint of food energy; difficulties in marginal land exploration, high cost of economic input; dispersed distribution of stalk resources, difficulties in collection	Difficulties in waste oil collection, and low quality; the planting of oil plants at the stage of demonstration, and it will take time to achieve large-scale utilization	Dispersed distribution of feedstock, and difficulties in collection and storage	Dispersed distribution of feedstock, and difficulties in collection and storage
Technology	Low rate of gas production and supply instability	Lagged technology of saccharification and fermentation, high energy consumption per unit	Immature technology of water–oil separation, and instability of oil quality; the level of equipment localization is low	Low level of technology and equipment localization, unreliability and instability of system	Low yield, high energy consumption, serious equipment wear and tear
Standard	Lack of unified digester construction standards and specifications	The existing standards "Denatured Fuel Ethanol" (GB18350-2001) and "Ethanol Gasoline For Motor Vehicles" (GB18351-2001) only suitable for starchiness fuel ethanol	Lack of specifications of production design and operation; imperfect system of standard, product inspection and certification	–	Lack of contamination emission standards for fossil energy combustion and biomass direct burning
Policy	–	The current preferential policies only suitable for five authorized production enterprises, unavailable to sweet grain sorghum and cellulosic bioethanol production	Strategic planning goal is small (utilization in 2010 will reach to 2.0×10^5 t. Current actual yield is 3.0×10^5 t/a with 3.0×10^6 t/a of production capacity)	Unavailable to subsidized special funds, and enterprises can not get value-added tax deduction	Lack of economic incentive mechanisms specified to biomass briquettes fuel technology
Market	–	At the stage of "Production-based Sales, Planned Supply", a political closed operation	Cannot enter main marketing channel of gas station	–	–

bioethanol industry in China is the difficulties in realizing the stabilization of feedstock supply in a short term.

4.2. Instability of industrialization and high cost of production

Economic profit is the key motive of industries development, and is the ultimate goal of the industry entity. China's Bioenergy technology is immature, equipment is relatively lagging, and materials and energy consumption is high, which is reflected as follows: (1) High fixed capital investment. For example, the installed capability of biomass power generation is low, and fuel supply is seasonal dependant. It is necessary to build an exclusive station for fuel collection and storage, and to provide facility for collection, storage and transportation. This means the high investment and fixed cost. (2) Instability of production technology, and high materials and energy consumption. Bioethanol production process in China is that of spray liquefaction, separate saccharification, and semi-continuous fermentation. Compared with the technologies in the USA, the efficiency of feedstock conversion is low, and the consumption of materials and energy per unit is high (Table 8). (3) Difficulty in collecting feedstock, and random market price. China's crop straw resources are abundant with 7.69×10^8 t of annual yield. However, they are distributed on 1.3×10^8 ha area of plantation, which result in a big collecting radius and high economic cost (Fig. 4). In addition, the increasingly high price of straw is also one of the main reasons for high production cost of bioenergy.

4.3. Inadequate industry-standard system

Industry standard is the gist and guideline to market access. China's bioenergy industry-standard system is inadequate. In the bioethanol industry, the implemented national standards *Denatured Fuel Ethanol* (GB18350-2001) and *Ethanol Gasoline For Motor Vehicles* (GB18351-2001) are only suitable for starchiness fuel ethanol. The increasingly emerging sweet sorghum ethanol and cellulosic ethanol industries now are in lack of standards for market admittance.

In the biodiesel industry, *Biodiesel Blend Stock for diesel engine fuels (BD100)* (GB/T20828-2007) is the only standard implemented in China [56]. But the enforceable quality standards for widely used biodiesel B5 and B10 are absent. The manufacturers establish their own company standards, which results in a chaotic product-standard market, uneven biodiesel quality, and therefore, it is difficult to sell at gas stations and main marketing channel. This is one of the key constraints for the development of biodiesel industry.

4.4. Lack of incentive mechanism, imperfect of policy system

Policy support is the key and initial impetus of industries development. Chinese government pays great attention to the development of renewable energy industry, and has enacted and implemented a series of laws, regulations and policies, in order to hasten the development and utilization of renewable energies including bioenergy. However, specific to the field of bioenergy, it is obviously deficient in governmental policy support and incentive mechanisms. For example, the government has enacted and implemented the *Interim Measures on Special Fund Management for Development of Renewable Energy*. But the detailed implementation of rules and particular operational procedures by way of financially supporting renewable energy research and development, standards establishment, and demonstration projects has not yet been promulgated. This made biomass power generation projects unavailable to the special fund.

Table 8
Comparison on materials' consumption per unit of bioethanol [54].

	Material consumption (t/t)	Heat energy (MJ/kg)	Coal consumption (kg/kg)	Steam consumption (kg/kg)	Water (t/t)	Electricity (kWh/t)
China	3.3	33.4	1.45	8.0	12	500
USA	2.8	16.8	0.73	4.0	1.8	350

4.5. Unsound follow-up service mechanisms

Follow-up management service is an important part of industries development. In recent years, although the establishment of China's bioenergy industry management and technical service system has gained some achievements, the basic problems of weak management service system have not yet been solved. In the biogas domain, digester-construction level is uneven and there is a lack of unified technical standards and criterion. The service system coverage is low. The coverage of biogas service system is 85.9% in county areas, and only 18.9% in town areas [57]. This is far from the objectives proposed by *National Rural Biogas Service System Program* that proposed that during the period of 11th Five-year Plan, the coverage of biogas technical service in county areas will reach 100% in the suitable areas of China, and will exceed over 70% in town areas.

5. Advice on bioenergy industries development in China

In light of the China's bioenergy industries development status and problems mentioned above, based on sustainable development of bioenergy industry, the countermeasures to develop China's bioenergy industries are proposed as follows:

5.1. Strengthen strategic research and improve industries development policy and plan

The goals of strategic planning play an important role in the orientation and guidance of industries development. Chinese government has enacted policies and planning, such as *Middle-and-long-term Development Plan For Renewable Energy* and *The 11th Five-year Plan of the Development of Renewable Energy*, which proposed the objectives that in the year of 2010, the total installed capacity of biomass power generation will reach to 5.50×10^6 kW, annual utilization of biomass briquettes fuel will reach to 1.0×10^6 t, that of biogas will be 1.9×10^{10} m^3, that of increased non-food bioethanol will be 2.0×10^6 t, and that of biodiesel will achieve upto 2.0×10^5 t. In the view of the current situation, the goal settings of some bioenergy industries, such as briquettes fuel and biodiesel, are short of practical guidance, which leads to tardiness of industries development, and its fall into damping status. In the premise of guaranteeing food security, realizing recycle economy and ensuring ecological balance, and promoting the harmonious and orderly development of bioenergy industry, the way to establish bioenergy development strategic goals and planning is one of the key problems to be solved firstly and foremostly in the development of bioenergy industrialization from national strategic level.

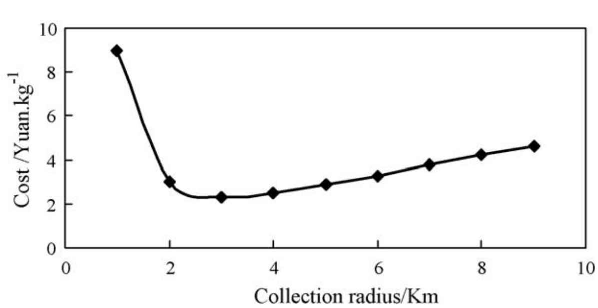


Fig. 4. Relationship between collection radius and costs [55].

In the research of strategic goals for bioenergy industries development, combined with resources and technology condition, encircling the industrial economy and target market, in accordance with the type of bioenergy industries, it is necessary to establish practical guiding ideology and strategic goals, to design the industrial layout and base-construction planning for non-food bioenergy production and cultivation, to enact the implementation program and related policies and regulations for the mixture, storage, transportation, distribution, and usage of bioenergy products, to standardize the market order, and to guide the sound and orderly development of the industry. Meanwhile, it should adjust the current relationship between government and enterprises in order to ensure enterprises' autonomous behaviors in the process of policy implementation.

5.2. Increase scientific research input and persist in technology independent innovation

Bioenergy is an emerging industry with high technical content. Presently, although China's bioenergy production technology has made some progress, the research and development of many key techniques and equipment, such as bioethanol enzyme technology and biodiesel production equipment, have not yet been broken through, which are important factors for the high cost and low market competitiveness of bioenergy production. It is necessary for government and research departments to increase the capital input for research and development of bioenergy technology, to create favorable conditions, and to overcome the technical difficulties. In the process of technical research and development, it should strengthen the industrial chain cultivation, extension and linkage as the core, to enhance technical research and development, and to strengthen industrial competitiveness. Specifically, it is necessary to involve bioenergy fundamental research, technology development and industrialization into national science and technology development plan, so to arrange special studies in the projects of high-technology industrialization and major equipment support, to support national research institutions and enterprises to increase innovation capability in core technologies of bioenergy, and to promote the formation of the core competitiveness of independent innovation by means of productive service innovation.

5.3. Establish product quality standard and improve industry-standard system

The establishment of industry-standard system is one of effective protective measures for sustainable industrial development. In 2001 and 2007, Chinese government established national quality standards for bioethanol and biodiesel. In July 2008, *the National Technical Committee on Fuel-ethanol and Denatured Fuel-ethanol of Standardization Administration of China* has been established and will be in charge of revisal of national standards for denatured fuel-ethanol and fuel-ethanol [58]. But as a whole, the industry-standard system of China's bioenergy is unsound, and product market is chaotic. The government should take measures

to study, establish, revise and improve the national standards for bioenergy industry; to establish national product quality standards for biodiesel B5, B10, B20 and bioethanol E90, E85 and E80; to focus on the establishment of national standards for liquid biofuel antioxidant additives, product quality, process flow and process design, and establishment of industrial technical specifications for product analysis and testing, fire protection, raw material storage, collection and disposal of production wastes; to establish management and security monitoring systems for the taches of mixture, storage, transportation, distribution and usage; to standardize the marketing pace for bioenergy products; and to provide pursuant law enforcement for each department hierarchy of quality and technology supervision. At the same time, in order to establish national standards for product quality, it is necessary to promote the enterprises actively to participate in international standards establishment, and internationalization of the national standards, which will be helpful to create a good international competitive environment for the development of China's bioenergy industry.

5.4. Open markets and promote market-oriented industry

The ultimate goal of industry development is to follow the rules of market economy to achieve the commercialization of financing, production, distribution and other aspects of the market. At present, the development of China's bioenergy industry is completely dependent on government support, which were carried out by the model of *Production-based Sales*, *Planned Supply*. In order to promote long-term effective development of the bioenergy industry, it should open the markets gradually, encourage various ownership enterprises to enter bioenergy production and marketing channels, use products future price mechanism to provide a hedge for bioenergy manufacturers, create a diversified market competition system, form a market operation mode which is mainly based on revenue and price adjustment with gradual supplement of financial subsidies, and promote normalization and market-orientation of bioenergy industry. Moreover, keeping in line with the targets of fair competition between small-and-medium-sized enterprises and large enterprises, and with the target of nationalization of the main treatment to state-owned, private, foreign, and other property rights it is necessary to promote anti-monopoly tendencies and push forward the formation of market competition pattern in the bioenergy industry.

6. Conclusion and prospect

With the increasingly exhausting fossil energy and the growing voice for reduction of greenhouse gas emission, the development of bioenergy industries has become an important strategic choice for sustainable energy development all over the world, and bioenergy industry has become one of emerging industries arousing global interest. The Chinese government attaches great importance to promote the development of bioenergy industry, with the efforts of enacting related laws and regulations, promulgation of relevant fiscal and taxation policies, and establishment of product quality standard and market regulation systems. Under the guidelines of national policies, biogas, bioethanol, biodiesel, biomass power generation, biomass briquettes fuels and other bioenergy industries have made greater progress, and maintained a good developing momentum. However, the weaknesses are highlighted gradually, such as shortage of feedstock supply, lagged equipment, high production costs, unsound industry-standard system, and chaotic market management. To promote the sound and orderly development of bioenergy industries, suggestions for bioenergy industries development have been proposed in light of China's bioenergy industries development status and existing problems: (1) strengthen strategic research and improve industries development policy and planning; (2) increase scientific research input and persist in technology independent innovation; (3) establish product quality standard and improve industry-standard system; and (4) open markets and promote market-oriented industry.

In recent years, China's oil import is growing year by year, and the external dependency is high. It is projected that China's oil demand will reach to 4.1–5.5 $\times$ 10^8 t by 2020, and the external dependence will reach to 60%. The balance between energy supply and demand of China will be a focal point in the future. The growing shortage of fossil energy supply will provide a broad market prospect for the development of bioenergy industries. In the future, with scientific and technological progress, and economic and social development, China's bioenergy yield will be rapidly increased, and the cost will be further reduced. There is a broad prospect for the development of bioenergy industries in China.

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References

[1] Demirbas A. Biomass resource facilities and biomass conversion processing for fuels and chemicals. Energy Convers Manage 2001;42:1357–78.
[2] Yamamoto H, Fujino J, Yamaji K. Evaluation of bioenergy potential with a multi-regional global-land-use-and-energy model. Biomass Bioenergy 2001;21:185–203.
[3] Zhenhong Y, Chuangzhi W, Longlong M. Principle and technology of Biomenergy utilization. Beijing: Chemical Industry Press; 2005.
[4] McKendry P. Energy production from biomass. Part 1. Overview of biomass. Bioresour Technol 2002;83:37–46.
[5] Cai J, Liu R, Deng C. An assessment of biomass resources availability in Shanghai: 2005 analysis. Renewable Sustain Energy Rev 2008;12:1997–2004.
[6] World Energy Council 1994. New renewable energy resources. London; 1994.
[7] Boyle G. Renewable energy power for a sustainable future. Oxford, UK: Oxford University Press; 1996.
[8] Koh LP, Ghazoul J. Biofuels, biodiversity, and people: understanding the conflicts and finding opportunities. Biol Conserv 2008;141:2450–60.
[9] Elghali L, Clift R, Sinclair P, et al. Developing a sustainability framework for the assessment of bioenergy systems. Energy Policy 2007;35:6075–83.
[10] Han JY, Mol APJ, Lu YL, et al. Small-scale bioenergy projects in rural China: lessons to be learnt. Energy Policy 2008;36:2154–62.
[11] Imported 163 million tons of crude oil in 2007 in China, petroleum external dependency will reach to 50%. http://oilsyggs.mofcom.gov.cn/article/gjhyxw/200801/17511_1.html.2008-01-02.
[12] Exploitable reserves reach to 2 billion in China, with 95 million tons of reserves were verified last year. China Environment News; 2007-04-05.
[13] National Bureau of Statistics of China. China statistical yearbook of 2007. China Statistics Press; 2007.10.
[14] BP Global Energy Statistics 2007; 2007-07-02.
[15] National Development and Reform Commission of China. China's National Climate Change Programme; 2007.06.
[16] Zhang L. A changing pattern of regional CO_2 emissions in China. Geograph Res 2006;25(1):1–9.
[17] Zhou XP, Xiao B, Ochieng RM, et al. Utilization of carbon-negative biofuels from low-input high-diversity grassland biomass for energy in China. Renewable Sustain Energy Rev 2009;13:479–85.
[18] Wang XH, Feng ZM. Biofuel use and its emission of noxious gases in rural China. Renewable Sustain Energy Rev 2004;8:183–92.
[19] Zhang PD, Yang YL, Shi J, et al. Opportunities and challenges for renewable energy policy in China. Renewable Sustain Energy Rev 2009;13(2):439–49.
[20] Dai L, Qin SP. Bioenergy: new growing point of energy industry in future. Environ Protect 2007;384(11):29–31.

[21] Liao CP, Yan YJ, Wu CZ, et al. Study on distribution and quantity of biomass residues resource in China. Biomass Bioenergy 2004;27:111–7.
[22] Yang YL, Zhang PD. Relation between woody energy development and sustainable development of economy and society. Renew Energy Resour 2008;26(3):102–5.
[23] Zhang PD, Yang YL, Li GQ, et al. Energy potentiality of crop straw resources in China. Renewable Energy Resour 2007;25(6):80–3.
[24] National Bureau of Statistics of China. China statistical yearbook of 2008. China statistics press; 2008.09.
[25] Weng W, Yang JT, Zhao QL, et al. Current situation and developing direction of straw utilization technology in China. China Resour Comprehens Util 2004;(7):18–21.
[26] Peng L, Wang DY. Estimation of annual quantity of total excretion from livestock and poultry in Chongqing Municipality. Trans CSAE 2004;20(1): 288–91.
[27] Wang FH, MA WQ, Dou ZX, et al. The estimation of the production amount of animal manure and its environmental effect in China. Chin Environ Sci 2006;26(5):614–7.
[28] Ning P. Solid waste disposal and treatment. Beijing: Higher Education Press; 2007.
[29] Zhang PD, Li XR, Yang YL, et al. Greenhouse gas mitigation benefits of large and middle-scale biogas project in China. Trans CSAE 2008;24(9):239–43.
[30] Ministry of Finance of China. Provisional measures for administration of the subsidy capital for crop straw energy utilization; 2008-10-30.
[31] Deng X, Zhang YL. Development of bioenergy and its impacts on future agriculture. J Agric Sci Technol 2008;10(2):1–5.
[32] Gautama R, Baral S, Heart S. Biogas as a sustainable energy source in Nepal: present status and future challenges. Renew Sustain Energy Rev 2009;13 (2):248–52.
[33] Liu DY, Zhu LQ. Current situation and development strategy of biogas industry in Guangxi. Guangxi Agric Sci 2008;39(4):445–8.
[34] Liu XJ, Wang HZ. Current situation and prospect of bioenergy. Impact Sci Soc 2008;3:5–9.
[35] Wang G, Liu W, Wang X, et al. Current status and prospect of biogas technology in China. Appl Energy Technol 2007;12:13–5.
[36] Wang JC, Dai L, Tian YS, et al. Analysis of the development status and trends of biomass energy industry in China. Trans CSAE 2007;23(9):276–82.
[37] National Development and Reform Commission of China. China's policies and actions for addressing climate change; 2008.10.
[38] Ministry of Agriculture of PRC. Notice about implemented newly-increased agriculture investment promptly, to do the reserve work of project well; 2008-11-4.
[39] Tian YS, Sun LY, Zhao LX. Analysis on development condition of Bioethanol in China. Chin Univ Technol Transfer 2008;3:72–5.
[40] Wei ZH. The way of China's bioethanol development. Econ Anal Chin Petrol Chem Ind 2007;3:46–9.
[41] Analysis on Current situation of bioethanol industry in the world; 2007-10-19. http://www.in-en.com/newenergy /html/newenergy-09540954931306-51.html.
[42] Xu XJ, Wang XH, Jin MF, et al. Research advance in ethanol production using sweet sorghum. Modern Chem Ind 2008;3:17–21.
[43] The project of using bioenergy sweet sorghum stalk to produce ethanol project started; 2007-10-11. http://www.agri.gov.cn/dfxxlb/jlxxlb/t20071011_901692.htm.
[44] Investigation on the suspension of non-food bioethanol project of China Oil and Food Import and Export Co.; 2008-07-28. http://www.86ne.com/Biomass/200807/Biomass_150482.html.
[45] Hu LH, Zhen WJ, Shan ZH. Progress and prospect of cellulosic ethanol. Modern Chem Ind 2008;S2:651–3.
[46] National Development and Reform Commission of China. Middle and long-term programs for renewable energy development; 2007.08.
[47] Liu J, Wu JG. Perspectives and prospects of biofuels. Acta Ecol Sin 2008;28(4):1339–2353.
[48] Li ZJ. On the guidelines and policies for biodiesel oil industry in China. Chin Soft Sci 2008;4:11–5.
[49] Zhang LB, Li CZ, Ou RM, et al. Current situation and development prospect of biodiesel industry. Hunan Forest Sci Technol 2008;35(2):70–3.
[50] China's biodiesel trade investment value report of 2008. http://www.bioon.com/bioindustry/bioenergy/374907_4.html.2008-09-29.
[51] Chen YS, Mu SL, Zhu DW. Development status of biomass briquettes fuel industry in China. Solar Energy 2006;4:16–8.
[52] Zhang BL, Wang XT, Yang SG. Key problems in production and application of straw densification briquetting fuel (SDBF). Trans CSAE 2008;24(7):296–300.
[53] The per capita plough in China is reduced to 0.0933 hm^2. http://news.xinhuanet.com/politics/2006-04/11/content_4412457.html.2006-04-11.
[54] National Development and Reform Commission of China. China biological industry development report of 2007; 2008.01.
[55] Li G, Wang GH. Economical and policy analysis in the industrialization of biomass briquette fuel. Trans CSAE 2006;22:142–5.
[56] Liu JL, Jiang JC. Statement on biomass energy standard system—biofuel ethanol standard progress. Biomass Chem Eng 2006;40(5):53–7.
[57] Ministry of Agriculture of PRC. National statistical data of renewable energy in rural area of 2006; 2006.
[58] Liu B. National Technical Committee on Fuel-ethanol and Denatured Fuel-ethanol of Standardization Administration of China has been established. http://www.biotech.org.cn/news/news/show.php?id=62253.2008-07-05.

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